§20. On Circulating Power of Steady State Tokamaks

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Recently, the study on the improved confinement of tokamak plasmas has revealed the importance of the profiles. In particular, the rotation drive is one of the most important issues, because it is strongly related to the MHD stability and improved confinement. We study the efficiency of the rotation drive [1].

The ratio of the Bootstrap current, I_{BS}, to the total plasma current, I_p, is evaluated as $I_{BS}/I_p = 0.7\sqrt{a/R}\,\beta_p$. The circulating power to sustain the total current becomes very small, when β_p reaches the value $1.4\sqrt{R/a}$. The MHD stability should be improved by the rotation at such a high beta value. The rotation drive efficiency is the key. The rotation drive efficiency η_{rot} is defined as $\eta_{rot} = \langle v\rangle/P_{rot}$, where <v> is the average velocity of the plasma rotation and P_{rot} is the necessary power from the supply. It is determined by three issues:

$$\frac{v}{P_{rot}} \propto \frac{\text{velocity}}{(\text{dissipation}) - (\text{spontaneous drive})}.$$

The lower bound for the required power is given as $P_b = \frac{\mu_\perp}{a^2}\frac{v_b}{v_{th}} n_i T_i V_p \frac{(v_\phi - v_{\phi *})}{v_{th}}$, where $\mu_\perp$ is the shear viscosity, v_ϕ is the toroidal velocity, and V_p is the plasma volume. The off-set $v_{\phi *}$ is the spontaneous plasma rotation in the absence of the external torque. Necessary velocity is discussed in relation to . The limit against high-n ballooning mode is considerably improved if the condition $\omega_E \geq 1/3$ holds ($\omega_E = E_r'\tau_{Ap}/sB$, s:the shear parameter, rq'/q, τ_{Ap}: qR/v_A, v_A: Alfven velocity). By this value, transport coefficient is also predicted to be reduced by the factor 3.

In the absence of the spontaneous rotation, we obtain

$$P_b/P_{heat} \cong \mu_\perp/\chi \qquad (1)$$

which is in the range of 1/3 to 1/2. (Typical parameters of ignited plasmas, T = 10keV, β = 0.1, E_b = 1MeV, v_ϕ/v_A = 0.04) This level of the circulating power is not tolerable for the steady state tokamaks.

The spontaneous drive is also calculated. The spontaneous potential difference, $\Delta\phi = \phi(a) - \phi(0)$ is predicted to appear as

$$\frac{e\Delta\phi}{T} \approx \frac{3F^2}{2q} \qquad (2)$$

which is around 2 for the usual tokamak discharges.

In the ignited plasmas, energetic alpha particles are generated. This free energy source could be used for the rotation drive. the rotation due to this α-particle drive is estimated as

$$\frac{v_{\phi *}}{v_A} \approx \sqrt{\frac{\beta}{6}}\,\frac{\chi}{3\mu_\perp}\left(\frac{1MA}{I_p}\right) \qquad (3)$$

If the confinement time is improved so that I_p = 10 MA holds, then the spontaneous velocity is in the range of $v_{\phi *}/v_A \approx 10^{-2}$ is expected. The spontaneous drive in the burning plasma increases by the enhanced confinement.

1) K. Itoh et al., J. Phys. Soc. Jpn. 65 (1996) 760